COMPARATIVE EFFECT OF WASTE MATERIALS ON CHEMICALLY DEGRADED SOIL IN SOUTH WESTERN NIGERIA

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ABSTRACT

The present study examined the comparative effect of addition of calcium carbonate and waste materials with liming potential on the soil pH and other soil chemical properties of chemically degraded sandy loam soils (Ultisol, Iwo series). Soil samples (0-15 cm) were collected from two sites at the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife, Nigeria. The waste materials used were eggshell powder (ESP) and biochar (ESB), calcium carbide waste (CCW), and wood ash (WA). An assay of the wastes showed relatively high calcium carbonate equivalent. An incubation study was undertaken in the laboratory for four weeks with soil samples from the two soil types, treated with 0.25, 0.5 and 0.75 g of waste materials per 100 g soil. The results of physical and chemical properties revealed a low fertility soil. For example, the soil pH, soil organic matter, were 5.6, 1.27% and 5.3, 2.5% for the two soil types respectively. The calcium carbonate equivalence of ESP, ESB, CCW and WA were 103, 101, 123 and 59% respectively. Significant increase in soil pH and concentrations of some basic cations were observed after the addition of the waste materials. In addition, manganese and exchangeable acidity were significantly reduced in all the treated soils compared with the control, except soil treated with WA which could be attributed to low calcium carbonate equivalence as compared to other liming materials used in this study. The study established effectiveness of the waste materials used as good alternatives to the use of pure calcium carbonate and concluded that, any of these wastes (eggshell, wood ash and calcium carbide waste) can be used as an alternative source of liming for remediation of chemically degraded soils.

Keywords: Soil acidity, Soil pH, Waste materials, Liming, Incubation

INTRODUCTION

Soil acidity is one of the major causes of soil degradation and poses a serious limitation to sustainable agricultural production in the humid regions of the world, by decreasing the availability of most essential plant nutrients and increasing the impacts of toxic elements in soils (Barrow, 2017; Goulding, 2016; Iren *et al.*, 2021). Soil acidification is a common occurrence in humid tropics as well as the forested regions in the temperate zones of the world (Goulding, 2016). In Nigeria, approximately 50% of agricultural land is susceptible to soil acidity due to its kaolinitic nature, high weathering rate coupled with high rainfall intensity with resultant leaching of basic cations from the soil profile (Olufemi *et al.,* 2020). Other causes of soil acidity include the removal of harvested crops leading to the depletion of basic cations, hydrolysis of hydrous oxides of Fe and Al leading to the release of H+ into the soil (Goulding, 2016), and continued application of acidifying chemical fertilizers like Urea.

Soil acidity influences almost all soil chemical and biological processes, it controls plant nutrient solubility and availability, influences microbial activities, determines the vegetation and plant diversity and controls soil productivity (Adepetu *et al.*, 2014; Herrera and Perez, 2020). In relation to plant nutrition, soil acidity has been linked closely to toxic concentrations of aluminium (Al), hydrogen (H) and manganese (Mn) (Rahman *et al.*, 2018; Barrow, 2017). These ions often lead to low productivity when present in very high concentration in soils because they alter soil ionic balance by inhibiting the crop from getting the required essential nutrients, such as calcium, magnesium, and phosphorus, and moisture from the soil (Herrera and Pérez, 2020). Soil acidity reduces the concentrations of exchangeable cations such as Ca and Mg due to high concentrations of acidic cations, such as Al and Mn, on the exchange site.

Soil acidity can be properly managed to become productive through the use of appropriate liming materials. This involves the replacement of the hydrogen ions by basic cations. For a liming material to be effective, it should be able to displace H^+ and Al^{3+} from the exchange sites of soil colloids into the solution, these cations later react with the anionic component of the liming material to form insoluble precipitate (Barak *et al.*, 1997). Common liming materials include oxides, hydroxides, or carbonates of calcium and magnesium, or some unorthodox liming materials such as wood ash, calcium carbide wastes, flue dust, cocoa pod ashes, eggshell, oyster shells (Goulding, 2016). Other practices of ameliorating soil acidity include the use of acid tolerant crop varieties and application of farmyard manure (Golla, 2019). However, a universal liming material is calcium carbonate. Several chemical reactions occur when calcium carbonate is applied to acidic soils. The first step involves the dissociation of calcium carbonate into Ca^{2+} and CO_3^{2-}. The Ca^{2+} then replaces the H^+ from the exchange site while H^+ is released to the soil solution and then combine with CO_3^{2-} to form carbonic acid. The carbonic acid breaks down into the water with the liberation of carbon dioxide, which results in an increase in base saturation with a consequent increase in soil pH. Neutralizing soil acidity effectively requires the addition of an appropriate quantity of lime termed lime requirement.

The lime requirement is the quantity or amount of lime required to take a given soil from its level of acidity to a prescribed pH within a specified period and depends on calcium carbonate equivalence (CCE) (Bailey *et al.*, 1991). The CCE is expressed as a percentage of the neutralizing ability of an equal weight of pure $CaCO_3$ in meq per 100 g of soil. The lime requirement of any liming material with high CCE will be low compared to liming material with low CCE. Apart from neutralizing the soil acidity, the liming of soil also offers other benefits like the improvement in phosphorus solubility, increasing ionic strength, calcium and magnesium contents, as well as improving soil structure via clay flocculation and biological activities (Paradelo *et al.*, 2015; Goulding, 2016). In tropical areas dominated by variable-charge soils, liming can be used as a management tool to manipulate the surface charge, thereby controlling the reactions of nutrient ions and heavy metals (Barrow, 2017).

The availability of liming materials varies a lot in different parts of the world, as most of the liming materials are available to farmers in developed countries particularly ground limestone (Quiroga *et al.*, 2017). In most developing countries like Nigeria, most farmers cannot afford the high cost of ground limestone. However, available local waste materials such as wood ash, and calcium carbide wastes amongst others, could be used as alternative liming materials by the farmers. Previous studies (Goulding, 2016; Iren and Uwah, 2018) have reported the effectiveness of these liming materials in reducing soil acidity. However, little information is available on the effectiveness of eggshell powder and eggshell biochar, alongside other local liming materials, hence this study. It is hypothesized that the application of these local waste materials to acidic soils will increase the soil pH and decrease the exchangeable acidity.

Therefore, the objective of this study was to compare the effect of the application of calcium carbonate ($CaCO_3$) and some local waste materials on the chemical properties of chemically degraded soils.

MATERIALS AND METHODS

Soil sampling and treatments

Soil samples (0-15 cm) for this study were collected from two locations based on the previous use of chemical fertilizers at the Teaching and Research Farm, Obafemi Awolowo University, Ile-Ife (T&RF, OAU). The soil samples used for the study were collected from two different locations after prior confirmation of the acidity status. The first set of soil samples (Location A) were collected from the cassava plot at latitudes 7^{o}32′N – 7^{o}33′N, longitudes 4^{o}32′E – 4^{o}33′E, and 280 meters above sea level. The second set of samples was from the continuously cultivated arable plot at latitudes 7^{o}33′N – 7^{o}34′N, and longitudes 4^{o}33′E – 4^{o}34′E, and about 285 meters above sea level (Location B). The soils from the two locations belong to the Iwo series classified as a Ultisol (Okusami and Oyediran, 1985; Soil Survey Staff, 2014). The soil samples were air-dried, crushed gently, and passed through a 2 mm sieve to separate gravel content from the other components. The soil fraction of less than 2 mm was retained for laboratory analyses.

Wastes used as liming materials and their pre-treatment

The materials used for liming in this study were calcium carbide waste (CCW), wood ash (WA), Egg shell powder (ESP) and Egg shell biochar (ESB). Calcium carbide waste was collected from a panel beater's shop at Alafia Street, Osogbo, Osun State, wood ash was from a local food center in Ile- Ife while the eggshell was from Globus chick hatchery, Station village, Iwo Osun State. The $CaCO_3$ (Analytical grade, BOH Laboratory Supplies Poole, BH15 11D, England) which served as a reference was from the Soil Science Department of Obafemi Awolowo University (OAU). The raw eggshell was thoroughly washed with water and then air-dried. The ESP was obtained by oven drying at 105^{0}C for about 20 hours, then ground to powder using a pestle and mortar. The ESB was prepared by pyrolysis at 500^{0}C for 3 hours. Each of the wastes was sieved through 63 µm sized sieve to ensure a uniform degree of fineness (Adam and Barber, 1984)

Determination of the chemical composition of the liming materials

Due to the wide variation in the composition of waste materials used as liming materials, their neutralizing value is often measured against pure $CaCO_3$ to determine the calcium carbonate equivalence (CCE). To determine CCE, 1 g of the sieved waste materials (CCW, WA, ESP and ESB) was dissolved separately in 100 ml of 0.25 N HCl solution; the excess acid was then back titrated with 0.25 N NaOH to give a pink end point (Adepetu *et al.*, 2014). The CCE was determined from the concentration and the amount of the acid consumed:

($CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$; $HCl + NaOH \rightarrow NaCl + H_2O$). To determine elemental composition of the waste materials used as liming materials in this study, 1 g of liming material was digested with 20 ml of concentrated H_2SO4 for 2 hours and left overnight to cool completely. The digest was transferred into 50 ml volumetric flask, made up to mark with distilled water and the component elements (Ca, Mg, Na, K, Mn) were read on AAS (Zhang et al., 2002). For carbonate content determination, 5 g of liming material was weighed into 250 ml flask, 100 ml of water was added, mechanically shaken for 30 minutes, and filtered. To 50 ml of the filtrate, 3 drops of boric acid indicator was added to give light blue colour and titrated with 0.02 N H_2SO4 to colourless end point (Zhang et al., 2002).

Incubation study

An incubation study was undertaken to determine the lime requirement of different materials used. One hundred grams of air-dried soil sample in 100 ml beakers were treated with varying weights of each of the liming materials corresponding to milliequivalent weights (0, 5, 10 and 15) of $CaCO_3$ which was equivalent to 0, 0.25, 0.50, 0.75 g of liming material per 100 g of soil. The same rates were used for $CaCO_3$ and all the waste materials used in this study because the CCE of the waste materials were close to 100 except WA (i.e., CCW = 123%, ESP = 103%, ESB = 101% and WA = 59%). The amount of lime applied in the incubation study was the amount needed to change the initial soil pH to neutral pH. The experiment was arranged in a completely randomized design and replicated three times. Each beaker was moistened to 80% field moisture capacity and incubated at 20 - 22 ^{o}C for a period of 4 weeks. The pH of each treated beaker was monitored weekly. At the end of the 4th week, the soil in each of the beaker was air-dried, crushed and subjected to chemical analysis in laboratory to evaluate the effect of the various rates of lime applied on the chemical properties of the soils.

Soil analyses

Soil pH was determined with a glass electrode pH meter in a 1:2 w/v suspension of air-dried soil in 0.01 M $CaCl_2$ solution and distilled water, after a 30 minutes equilibration time (Peech, 1965). Soil exchangeable cations (Na, K, Ca and Mg), including manganese (Mn), were determined in the extract of 10 g soil with 100 ml 1 N neutral ammonium acetate solution and shaken for 30 minutes (Thomas, 1983). The concentrations of Na and K were determined by a flame photometer while Ca, Mg and Mn were determined using atomic absorption spectrophotometer (AAS). Exchangeable acidity was determined by the titration method (McLean, 1973). Organic matter (OM) was determined using a modified chromic acid digestion method (Nelson and Sommer, 1996), available phosphorus was determined using the Bray-1 method (Bray and Kurtz, 1945) as modified by Kuo (1996) while the particle size analysis was by hydrometer method (Bouyocous, 1962). The field moisture capacity was determined using the core method (Black, 1965).

Statistical Analysis

The data obtained were analysed using R – statistical software version 3.6.0 (R core Team, 2019). The data were fitted by a generalized linear model with fixed effects representing different treatments. Data were checked for normality and constant variance using Shapiro and Bartlett tests. Post-hoc multiple pairwise comparisons were analysed by Tukey's significance differences using the CLD function implemented in the R package emmeans. For all the analyses, the criterion used for statistical significance was $P < 0.05$.

RESULTS AND DISCUSSION

Physical and chemical properties of the soils used for the study

Results of the physical and chemical properties of the soils used for the experiments are presented in Table 1. The textural classes of soil samples collected from Locations A and B were sandy clay loam and sandy loam respectively, the pH values in 0.01 M $CaCl_2$ solution were 5.6 and 5.3 respectively, suggesting that these soils are slightly acidic. The available P values in both soils were very high, while the soil organic matter (SOM) for both was average. The exchangeable Ca and Mg are high while the exchangeable K and Na for both soils were extremely low. In acid soil, the microbial activities are most likely to be impaired thereby hinders organic matter mineralization and low solubility of essential plant nutrients for plant uptake (Paradelo, 2015). The high concentration of available P in these soils does not guarantee availability for plant uptake due to reactions of P with Fe and Al under acidic soil conditions. However, the addition of liming materials to these soils will enhance the solubility of P, similar to a previous study (Haynes and Naidu,1998).

Chemical characteristics analysis of wastes used as liming materials in this study

The results of chemical analysis of the wastes used as liming materials indicate that all the wastes contained a relatively high concentration of Ca, K, and CO_3^{2-} (Table 2). The CO_3^{2-} content of the wastes was slightly higher in wood ash and calcium carbide wastes than eggshell. The concentrations of Ca^{2+} and CO_3^{2-} obtained in the wastes were relatively substantial to justify their effectiveness as liming materials (Yanga *et al.*, 2018).

Table 1: Physical and chemical properties of soils A and B before liming

Property	SOIL A	SOIL B
Sand (%)	67.68	78.40
Silt (%)	10.16	7.80
Clay (%)	22.6	13.80
Textural class	Sandy clay loam	Sandy loam
pH (0.01 M $CaCl_2$)	5.6	5.3
Available P (mg/kg)	42.5	82.7
Exchangeable cations (cmol/kg)		
Calcium	3.67	1.79
Magnesium	2.44	0.96
Potassium	0.01	0.004
Sodium	0.01	0
Manganese (mg/kg)	19	25.8
Organic Matter (%)	1.27	2.5
Exchangeable acidity (cmol/kg)	0.6	0.6

Table 2: Chemical composition of waste materials used as liming materials

Liming material	Ca	Mg	K	Na	Mn	CO_3
	←		(mg/kg)			→
ESB	3.37	3.24	10.34	8.01	0.33	1.52
ESP	3.94	3.14	4.70	5.34	0.45	5.9
CCW	1.78	1.01	1.88	1.78	0.65	24.88
WA	5.37	4.02	1823.60	382.70	3.87	50.1

ESB = Eggshell biochar, ESP = Eggshell powder, CCW = calcium carbide waste and WA = wood ash

Effects of addition of liming materials on soil chemical properties after incubation

The results of incubation study showed that soil pH of the control treatment remained fairly constant throughout the incubation period (Table 3). However, the pH of all the treated soils increased significantly ($P \leq 0.05$) in the first week of incubation when compared with control treatment. The pH of treated soils with CCW in the first and second week increased with increasing levels of applied waste materials used for liming in this study. This result is consistent with the findings of Iren and Uwah (2018) where the addition of woodash as liming materials to an Ultisol in Southeast Nigeria increased the soil pH from 4.5 to 5.9. All the wastes used as liming materials proved to be effective in ameliorating soil acidity, suggesting that any of them could be used as alternative source of liming materials, especially when the cost of calcium carbonate is out of reach of many peasant farmers. In Soil A, addition of different waste materials significantly increased ($p<0.05$) soil pH from 5.6 to 7.3 (calcium carbonate, CC), 9.2 (calcium carbide waste, CCW), 7.5 (eggshell biochar, ESB and eggshell powder, ESP) and 8.0 (wood ash, WA), while similar trend was also observed in soil B. Application of any of these waste materials at a rate 5 cmol/kg (corresponding to 5,625 kg/ha) significantly increased the pH of the soils, and beyond this rate, pH started to decline or remained fairly constant, indicating the optimum liming rate to increase the initial pH of these soils to the neutral pH.

Table 3: Changes in soil pH following the addition of different rates of liming materials

Treatments	Soil A Weeks				Soil B Weeks			
	1	2	3	4	1	2	3	4
C	5.6a	5.5a	5.4a	5.4a	5.2a	5.3a	5.3a	5.3a
CC1	7.1bc	7.1b	7.1b	7.0b	7.0b	7.2b	7.1b	7.2b
CC2	7.1b	7.2b	7.2b	7.1b	7.1b	7.3b	7.2b	7.3b
CC3	7.1b	7.3b	7.1b	7.1b	7.1b	7.2b	7.2b	7.1b
CCW1	8.1e	7.9d	7.9bc	7.6bc	8.0c	8.0c	7.8bc	7.9c
CCW2	8.8f	8.4e	8.3c	8.3c	8.6d	8.1c	8.1c	8.1cd
CCW3	9.2g	8.9f	8.8c	8.5c	9.3e	8.8d	8.4c	8.4d
ESB1	7.0b	7.0b	7.3b	7.2b	7.0b	7.1b	7.1b	7.1b
ESB2	7.1b	7.2b	7.2b	7.1b	7.0b	7.1b	7.1b	7.2b
ESB3	7.1b	7.2b	7.3b	7.3b	7.0b	7.0b	7.0b	7.2b
ESP1	7.1b	7.1b	7.3b	7.2b	7.0b	7.0b	7.1b	7.0b
ESP2	7.2bc	7.3b	7.5bc	7.4b	7.0b	7.1b	7.2b	7.1b
ESP3	7.1b	7.3b	7.4bc	7.2b	7.0b	7.1b	7.2b	7.1b
WA1	7.4c	7.4bc	7.5bc	7.3b	7.2b	7.3b	7.3b	7.3b
WA2	7.7d	7.7cd	7.7bc	7.7bc	7.6bc	7.7bc	7.5bc	7.5bc
WA3	7.9de	8.0d	8.0c	8.0c	7.8bc	8.1c	8.0c	8.0c

Means with the same letters in the same column are not significantly different from each other at ($p \le 0.05$) according to Tukey's Honest Significant Different Test. Where C = control, CC1, CC2 and CC3 = Calcium carbonate at 5, 10 and 15 cmol/kg respectively, ESB1, ESB2 and ESB3 = Eggshell Biochar at 5, 10 and 15 cmol/kg respectively, ESP1, ESP2 and ESP3 = Eggshell Powder at 5, 10 and 15 cmol/kg respectively, CCW1, CCW2 and CCW3 = Calcium carbide waste at 5, 10 and 15 cmol/kg respectively, WA1, WA2 and WA3 = Wood ash at 5, 10 and 15 cmol/kg respectively

The addition of calcium carbide waste significantly increased ($p<0.05$) soil pH more than any other liming materials that were used including the reference sample (calcium carbonate), and this could be attributed to the fact that CCW had the highest calcium carbonate equivalence (123 %) among all the liming materials used in this study. The pH changes in ESB and ESP were not significantly different. The calcium carbonate equivalence of ESB and ESP are 103 and 101% respectively, showing that they have almost the same neutralizing values as $CaCO_3$. Hence, the reason for equal performance in improving the pH of the soils. Therefore, there is no need for charring of eggshell before using it as liming material, as this will eliminate the charring cost.

Generally, addition of different levels of liming materials did not significantly increase available P when compared with the control (Tables 4 and 5). However, the addition of treatments CCW3 and WA3 significantly increased available P when compared with control in soil B. When soil pH increases, the negative charges on the exchange site also increase, and P in the form of phosphate ion (PO_4^-) will be repelled by the exchange site thereby increasing its solubility and availability in soil solution, and that could explain the increase in available P recorded in some treatments in soil B. This is consistent with the results of previous studies (Barrow, 2017; Azeez *et al.*, 2020; Christensen *et al.*, 2021). Barrow (2017) reported increase in P availability following lime application and attributed this to increase in base saturation and surface charge of the soil colloids.

Exchangeable cations were little affected by addition of liming materials, especially in soil A. However, addition of ESB and ESP significantly increased exchangeable Ca and Mg in soil B compared with control (Tables 4 and 5). The waste materials used for liming in this study contained significant amount of Ca and Mg and when applied to acidic soils, increase the concentrations of these cations in soils, similar to previous reports (Azeez *et al.*, 2020; Barak *et al.*, 1997). Manganese concentrations were significantly reduced in soil A, and in treatments CC1, CC2, ESB2, ESB3, ESP1, ESP2, ESP3 and CCW1 in soil B, following the addition of different rates of waste materials. When lime is applied to acidic soils, H^+, Al^{3+} and Mn^{2+} from the exchange sites are dissociated from soil colloids, then H^+ is neutralized, and Al^{3+} and Mn^{2+} are precipitated in soil solution, thereby reducing the concentrations of these cations (Barak *et al.*, 1997; Barrow, 2017). The reduction of the concentrations of these acidic cations due to liming could also be caused by deprotonation of pH-dependent charge sites arising from either mineral (Fe and Al oxides and hydroxides) or organic (carboxyl and phenolic) components of the soil (Barrow, 2017; Paramisparam *et al.*, 2021).

The exchangeable acidity, H^+ and Al^{3+}, was significantly decreased ($p<0.05$) in ESB3, ESP1, ESP2 and CCW3 in soil A; and CC3, CCW2, CCW3, all levels of ESB and ESP in soil B (Tables 4 and 5). This result confirms the hypothesis that the addition of waste materials to acidic soils will reduce the exchangeable acidity. The same mechanism for the reduction of Mn ion in acidic soils after the addition of liming materials also holds for exchangeable acidity (H^+, Al^{3+}). The precipitation of these acidic cations due to an increase in negative charges on exchange sites arising from an increase in pH observed in this study could explain the significant decrease in exchangeable acidity, similar to a previous study (Onwuka *et al.*, 2016). Organic matter content was not significantly influenced by the lime addition, though higher values were recorded in lime-treated soils compared with the control.

Table 4: Chemical properties of soil A after 4 weeks incubation with different rates of lime

Treatments	Available P	Mn	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Exch. Acidity	Organic matter
	mg/kg		cmol/kg					%
C	36.4ac	18.7n	3.5b	1.3d	0.004a	0.004a	0.6b	1.3b
CC1	42.0ac	8.8b	1.9ab	1.2d	0.003a	0.003a	0.6b	1.6b
CC2	32.1ac	13.6f	1.9ab	0.3a	0.004a	0.004a	0.8c	0.8ab
CC3	25.1ab	10.5c	2.4ab	0.3a	0.003a	0.003a	0.6b	1.4b
ESB1	42.6ac	15.8g	2.5ab	1.1cd	0.008c	0.008b	0.4ab	2.0b
ESB2	27.8ab	13.2e	1.8ab	1.1cd	0.008c	0.008b	0.4ab	1.7b
ESB3	30.0ab	16.2l	1.7ab	1.2d	0.009c	0.009b	0.2a	1.5b
ESP1	30.2ab	15.4i	2.7ab	1.3d	0.008bc	0.008b	0a	1.5b
ESP2	28.5ab	18.4n	2.5ab	1.3d	0.008c	0.009b	0a	1.0b
ESP3	21.6a	16.8m	2.1ab	1.5d	0.009c	0.009b	0.4ab	1.4b
CCW1	32.3ac	7.3a	2.5ab	0.5ab	0.003a	0.003a	0.60b	2.2b
CCW2	45.5ac	14.0h	2.2ab	0.5ab	0.003a	0.003a	0.40ab	1.1b
CCW3	53.3bc	10.5c	2.2ab	0.8bcd	0.005ab	0.005a	0.00a	1.0b
WA1	44.7ac	12.7d	2.1ab	0.8bcd	0.05d	0.053c	0.5b	0.3a
WA2	52.9bc	15.9k	1.6a	0.9bcd	0.07de	0.078c	0.5b	1.4b
WA3	71.2c	13.9g	2.0ab	1.1cd	0.13e	0.13d	0.5b	1.6b

Means with the same letters in the same column are not significantly different from each other at ($p \leq 0.05$) according to Tukey's Honest Significant Different Test. Where C = control, CC1, CC2 and CC3 = Calcium carbonate at 5, 10 and 15 cmol/kg respectively, ESB1, ESB2 and ESB3 = Eggshell Biochar at 5, 10 and 15 cmol/kg respectively, ESP1, ESP2 and ESP3 = Eggshell Powder at 5, 10 and 15 cmol/kg respectively, CCW1, CCW2 and CCW3 = Calcium carbide waste at 5, 10 and 15 cmol/kg respectively, WA1, WA2 and WA3 = Wood ash at 5, 10 and 15 cmol/kg respectively.

Table 5: Chemical properties of soil B after 4 weeks incubation with different rates of lime

Treatments	Available P	Mn	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Exch. Acidity	Organic matter
	←mg/kg→		←cmol/kg				→	%
C	49.2ab	25.4e	1.8b	1.8b	0.016c	0.016c	0.6b	2.0bcdf
CC1	56.4ad	20.2b	1.3a	1.3a	0.017c	0.017c	0.4ab	2.8df
CC2	54.6ac	22.0c	1.2a	1.2a	0.016c	0.016c	0.6b	1.7ac
CC3	44.4a	26.0f	1.1a	1.1a	0.016c	0.016c	0a	2.4cdf
ESB1	66.2ad	26.4f	1.7b	1.7b	0.007b	0.007a	0a	2.2cdf
ESB2	56.8ad	20.3b	1.2a	2.7c	0.007b	0.007a	0.2a	3.0ef
ESB3	55.1ac	19.7b	3.1cd	3.1cd	0.008b	0.008a	0a	1.7ad
ESP1	58.7ad	18.5a	3.3d	3.3d	0.007b	0.007a	0.2a	2.8df
ESP2	50.9ac	19.5b	3.0cd	3.0cd	0.004a	0.004a	0.0a	2.4cdf
ESP3	63.2ad	23.1d	2.8c	2.8c	0.005a	0.005a	0.0a	2.6edf
CCW1	71.4bcd	22.3c	1.1a	1.4ab	0.016c	0.002a	0.40ab	1.8ad
CCW2	74.4bcd	25.3e	1.2a	1.6ab	0.016c	0.003a	0.0a	1.3ab
CCW3	79.5cd	25.1e	1.0a	1.7b	0.013c	0.001a	0.0a	1.9ade
WA1	62.6ad	27.2g	1.4ab	1.5ab	0.05d	0.05b	0.4ab	1.7ad
WA2	68.3ad	26.3f	1.6ab	1.6ab	0.07e	0.07b	0.5b	3.2f
WA3	89.5d	27.0g	1.4ab	1.7b	0.13e	0.13c	0.4ab	1.1a

Means with the same letters in the same column are not significantly different from each other at ($p \leq 0.05$) according to Tukey's Honest Significant Different Test. Where C = control, CC1, CC2 and CC3 = Calcium carbonate at 5, 10 and 15 cmol/kg respectively, ESB1, ESB2 and ESB3 = Eggshell Biochar at 5, 10 and 15 cmol/kg respectively, ESP1, ESP2 and ESP3 = Eggshell Powder at 5, 10 and 15 cmol/kg respectively, CCW1, CCW2 and CCW3 = Calcium carbide waste at 5, 10 and 15 cmol/kg respectively, WA1, WA2 and WA3 = Wood ash at 5, 10 and 15 cmol/kg respectively

CONCLUSIONS AND RECOMMENDATIONS

The study compared the effectiveness of local liming materials with calcium carbonate on soil chemical properties of acidic soils. All the waste materials used as liming materials in this study have equal potential with calcium carbonate to raise the soil pH from acidic conditions to a neutral level at the end of the incubation period. The reduction in Mn and exchangeable acidity is indicative of the effectiveness of most of the waste materials used in this study. The eggshell powder and biochar have almost the same liming potential, thus, there is no need for charring of the eggshell. Therefore, it can be recommended that in a situation where orthodox liming materials are not readily available or are out of reach of the farmers to procure, any of the waste materials evaluated in this study (eggshell, wood ash and calcium carbide waste) which had been found to be an effective liming material can be used as an alternative source of liming in restoring chemically degraded soils. Further studies on the effects of these waste materials on crop nutrient uptake should be explored in the greenhouse and on the field.

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